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Trade-off between environmental and economic implications of PV systems integrated into the UAE residential sector

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ABSTRACT

PV technology offers clean resource and environmental advantages over fossil-fuel-based electricity generation; however, it remains more expensive than conventional technology in most grid-connected applications. The trade-off between environmental and economic parameters represents a challenge for governments. The objectives of this study are: firstly, to review studies in relation to the use of PV systems in the Gulf region and secondly, to assess the trade-off between environmental and economic parameters that influence the value of building integrated photovoltaic (BiPV) technology applied into the UAE building sector. This work examines residential buildings and concludes that the economic viability of BiPV systems is subject to capital cost, system efficiency and electricity tariff. To be a cost-effective option in the UAE, subsidies for PV investments and reasonable electricity tariff must be implemented. It is suggested that BiPV systems offer cost reductions in both energy and economic terms over centralised PV plants, especially if the costs of saved operating energy and avoided building materials are taken into account. Each square meter of BiPV is capable of making a significant reduction in CO_2 emissions generated by conventional power plants. This will limit the impact of global warming on the UAE and others.

Contents

1. Introduction

The United Arab Emirates (UAE) is characterised by favourable geographical conditions and represents a major oil producing country. During the past few decades, the UAE has witnessed an unprecedented economic and social transformation. Oil proceeds have been used to modernise infrastructure, create employment and improve social indicators. Due to this expenditure, the UAE has become a major CO_2 emitter [1]. In one decade (1997–2006), the primary energy increased by almost 60% with a 15.3% increase between 2007 and 2008 [2]. While at the same time, the increase in CO_2 emissions due to energy use reached between 33% and 35%

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[3]. Today, the use of solar technologies is representing one of the most promising, reliable and environmentally friendly renewable energy technologies, which has the potential to contribute significantly to the energy and environmental system in the UAE region. A technical field study carried out by the Centre Suisse d'Electronique et Microtechnique (CSEM)-UAE Innovation Centre [4] found a linear increase in photo-generated current due to increase in solar radiation. However, it was observed that the PV module efficiency dropped by 3–4%, compared with standard test conditions (STC), due to the high range of PV module temperatures (50–60 °C) and the power output changed due to high ambient temperature on the site. Another study [5] showed that if BiPV was applied into commercial buildings, a considerable amount of electricity could be saved. Consequently a large amount of CO_2 emissions could be reduced. The current research assesses the value of BiPV systems in the UAE residential sector and highlights parameters influence such value.

Many studies and experiments in the Gulf region have suggested different assumptions and presented numerous results. Studies in energy policy [6–9], on the one hand, are very optimistic about the use of renewable energy stating that renewable energy sources are expected to play a greater role in the future based on the rich natural potential of the region [10]. Moreover, the use and development of renewable energy technologies can make a significant contribution to improving environmental protection and to guaranteeing continuing oil supplies in conditions of stability and security in the Gulf region [11].

On the other hand, experimental and technical studies in renewable energy are more conservative. Recent studies in Saudi Arabia claimed that despite the abundant availability of solar energy PV systems alone could not satisfy building loads on a 24-h basis. Nevertheless, hybrid systems with different combinations of wind and photovoltaic (PV) panels were able to provide a great portion of the energy demand [12]. In general, PV technology could not be considered as a cost-effective technology with the current energy price and PV system cost [13]. As for Bahrain, the adoption of solar technology was said to be very advantageous, albeit with a number of drawbacks, while the use of wind energy was not encouraging [14]. At the same time, the grid connected PV systems in Kuwait could be a promising technique to enhance the performance of traditional grid utility systems. Such systems were expected to be economically feasible [15]. In an attempt to optimise the electrical load pattern using grid connected PV systems, the peak load was found to matched the maximum irradiance level in Kuwait, which would emphasise the role of using PV stations to minimise the electrical load demand coupled with achieving a significant reduction in peak load [16]. However, if PV stations were proposed to be installed, the capital cost per PV installed peak watt must be less than the 90th prices [17]. In order to emphasise this result, a sensitivity analysis was performed to the capital cost per installed PV peak watt, discount rate, and operating peak hours [18]. The present Qatari PV stations, however, were indicated as not economically feasible compared with conventional gas turbine stations [19]. In Oman, the PV technology was examined and its effectiveness proven, to a certain extent. It held great promise for electricity generation but, at the current time, was a relatively high capital-cost process [20].

Clearly, the majority of studies in the Gulf region focused on large scale applications and dealt mainly with technical and economic aspects. The value of PV technology, however, needs to be evaluated in the light of environmental and even social parameters [21]. Technical, economic and environmental parameters play a significant role in the assessment of PV value. Such parameters were considered in the evaluation of PV technology as electricity sources for many countries with different conditions [22]. The cost effectiveness of PV technology and its impact on the environment, for example, was demonstrated in Jordan [23]. The same situation can be seen in Brazil where the BiPV technology was presented as an interesting potential for decentralised generation in urban areas [24]. However, this was not the situation in Serbia, where the integration of PV into the envelope of urban buildings was found to be not economically viable [25]. The same situation was repeated in Montreal. Due to the high cost of the solar technologies and the low cost of electricity, financial payback of BiPV was never achieved [26]. While at the same time, techno-economic assessment of a BiPV system in Greece concluded that the high initial cost of the BiPV system was a prohibitive factor for the implementation of PV projects and there was no incentive for central grid-connected consumers to purchase a PV system for their electricity supply [27]. However, technical optimisation of PV panels might influence the economic viability [28]. If environmental benefits were considered then the specific investment would soon be worth considering [29]. From this perspective, the integration of PV panels into buildings in China helped in producing electricity and cutting down electric lighting and cooling energy requirements to benefit the environmental, energy and economic aspects [30].

Based on the above, the consideration of technical and non-technical factors plays a significant role in the accuracy of PV value. Ignoring any of these factors may make solar PV to be seen as the greatest or worst opportunity of electricity generation. According to a recent study in the UK [31], the trade-off between environmental and economic implications enables PV technologies to be cost effective. This trade-off can be reduced when the benefits of BiPV are considered. The study suggested that BiPV systems offer double benefit of reduced economic costs and improved environmental performance when compared with centralised PV plants. Another study in the UK [32] indicated that PV technology was not viable in comparison with conventional electricity sources. However, it was viable in the sense that it provided significant environmental benefits over conventional electricity sources on the grounds that adoption of such a technology would have social benefits outside the sphere of monetary evaluation.

The present work evaluates the impact of environmental benefits and economic parameters on the value of BiPV technology for the UAE residential sector. It assesses the BiPV from an environmental and economic point of view and identifies environmental and social parameters that stimulate decisions of UAE policy regarding the PV technology.

2. Methodology

A three step procedure was followed in assessing the BiPV value including technical study, economic assessment and environmental analysis.

2.1. Technical study

Abu Dhabi and Sharjah were chosen to represent different emirates in the UAE. Each has its own economic and social situation. As depicted in Table 1, a prototype residential building was developed and a building integrated photovoltaic (BiPV) system then designed. The PV system was assumed to be integrated into the skin of the prototype house. The PV panels were first applied into the roof with a 15 cm air gap and then into the southern wall with a tilt angle of 24°. Sanyo single crystalline silicon solar cells were used and assumed to have an efficiency of 15.2%. The specification of the PV system are given in Table 2. The Energy-10 simulation software [33] was used to model the BiPV performance and its impact on building energy behaviour under the real weather conditions of the studied emirates.

Table 1
Prototype building.

Description	
No. of floor	2
Total area	350 m^2
Floor height	4.0 m with slab
External walls	150 mm concrete masonry units (CMU) block-24 mm of plaster inside and outside
Roof	200 mm concrete, slab 50 mm screed, 50 mm sand and 10 mm ceramic tiles
Glazing area	North: 25 m^2 East: 23 m^2 South 23 m^2 West: 23 m^2
Loads	
Cooling	33,600 kW h/yr (70%)
Refrigeration	3000 kW h/yr (6%)
Lighting	6969 kW h/yr (14.5%)
DHW	2400 kW h/yr (5%)
Miscellaneous	2220 kW h/yr (4.5%)
Total	48,156 kW h/yr

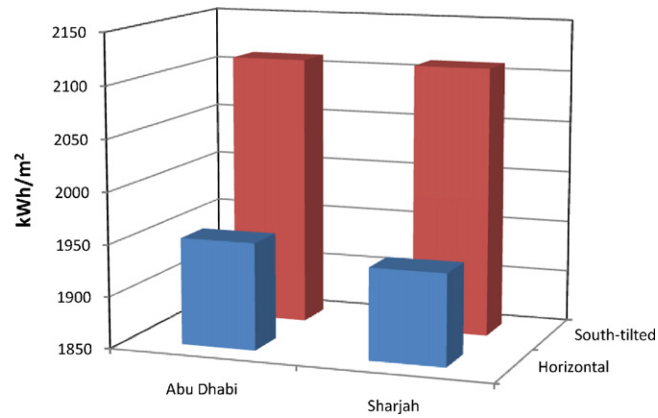

Fig. 1. Annual irradiance on horizontal and south tilted planes.

2.2. Economic assessment and environmental analysis

The assessment of BiPV system followed the Guidelines for the Economic Evaluation of Building-Integrated Photovoltaic Power Systems of the International Energy Agency PVPS Task 7: Photovoltaic Power Systems in the Built Environment [34]. A number of economic and financial feasibility indices were used, namely, the payback time (PBT), net present value (NPV) and internal rate of return (IRR). In terms of environmental impact, the carbon emission index was use. The total CO_2 emission was obtained by multiplying the amount of electricity (saved or generated by BiPV systems) by the conversion factor of fuel.

3. Result and assessment

In this assessment, technical parameters are studied, economic indices calculated and environmental benefits analysed.

3.1. Technical study

For credibility, a broad range of aspects should be considered, as there are multiple functions. These functions include electricity supply, construction materials and thermal insulation. Taken into account thermal performance of BiPV systems and building material replacement enables to provide an overall investigation for BIPV applications [35]. Recognising such benefits can improve the value of BiPV systems.

3.1.1. Electrical benefits

The value of PV output is subject to three major factors: the conversion efficiency of PV system, the amount of illumination that the system receives and the local climatic conditions. Statistics show that the UAE is one of the most productive solar regions. Fig. 1 illustrates the annual irradiance on horizontal and south tilted planes for the two studied emirates. Clearly, both emirates are blessed with high irradiance levels. These levels represent a sufficient environment for utilising solar energy in the UAE using PV technology [36]. The performance of the PV technology, however, needs to be evaluated, considering many parameters such as PV system cost and efficiency as well as the impact of real climatic conditions. Fig. 2 shows the efficiencies of PV modules due to real weather conditions in the two emirates. The high ambient temperatures of the UAE (48 °C in coastal areas and above 50 °C in southern regions) cause the system efficiency to drop from 15.2% to 10.3% and 9.8% in Abu Dhabi and Sharjah respectively. As a result, the output of the PV system was found to be less than estimated based on the standard test conditions (STC). There is agreement between these results and findings reported by the CSEM-UAE Innovation Centre LLC [4] where the PV module efficiency dropped and the power output changed due to high ambient temperature. Fig. 3 illustrates the total PV output due to real operation conditions.

3.1.2. Constructional benefits

PV panels represent integral components of the building envelope. The common cladding materials such as stone, brick and stucco can be replaced with PV panels. This substitution effect means that while there is a growth in cost due to the PV panels, there is also a reduction due to the number of cladding brick or plaster panels required for the cladding. Table 3 shows prices of different wall cladding systems and roofing materials. In the UAE, plaster (stucco) and sand-lime bricks are often used to clad walls, while stone coated roof tiles and water resistance sheets are often

Table 2
Specifications of the PV system.

Module	Sanyo_HIP-H097		
Description		Length (m)	Width (m)
Rated power	175 Wp		
Area	1.15 m^2	1.31 m	0.88 m
Efficiency	15.2%		
PV life	25 year		
First 10 years	100% performance (guaranteed by the manufacturer)		
After 10 years	80% performance (guaranteed by the manufacturer)		
PV cell type	Crystalline		
Max power point voltage	52.9 V		
Orientation of PV	PV array area (m^2)	Total PV rated output (kW)	
South	97	14.7	
Roof	202	30.63	

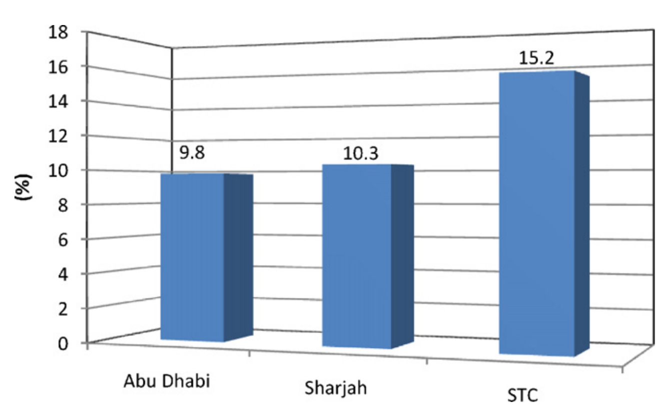

Fig. 2. Efficiencies of PV modules due to real weather conditions.

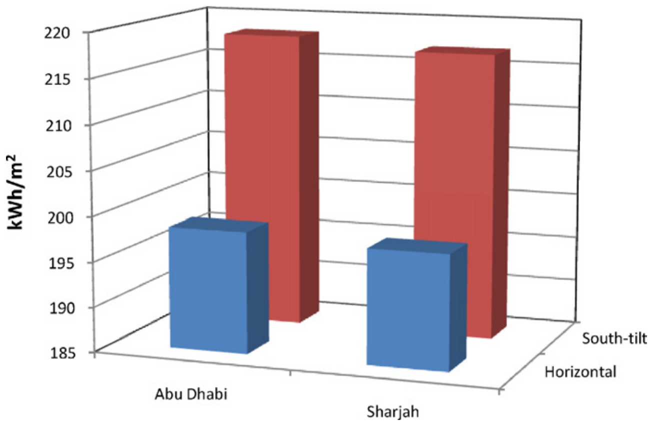

Fig. 3. PV output due to real operation conditions.

Table 3
Prices of different wall cladding systems and roofing materials.

Type of cladding	Price ($\$/m^2$)
Plaster (Stucco)	5–10
Brick/wall cladding	50–75
Wall porcelain tiles	15–25
Brick Veneer	30–45
stone coated roofing tile	15–25
PV	500–1500

used to cover roofs. The tabled prices include martial costs and labour charge.

3.1.3. Thermal benefits

PV panels can form parts of construction elements as thermal insulators. Such panels have significant influence on the heat transfer through building envelope because of the change in thermal properties. It can alter the cooling loads as well as the general operating energy [37]. Fig. 4 shows the reduction in annual cooling energy and total electricity consumption due to integrating PV panels into the developed prototype house. As a result, decreases from 20% to 30% have occurred in heat gains. The energy used for cooling the building is consequently decreased, leading to a reduction in the total electricity consumption by about 10–15%. An assumption can be made that each square meter of PV panels saves an amount equals to the total electricity savings divided by the total PV area. Therefore, about 125–145 kW h/yr of electricity can be saved due to each square meter of PV.

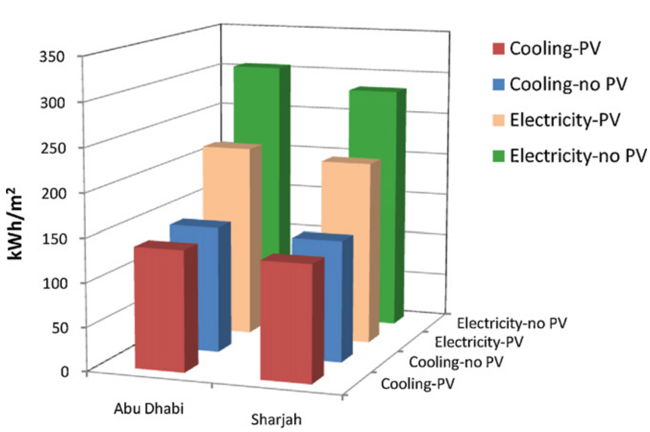

Fig. 4. Reduction in total electricity consumption.

Table 4
Financial data use for economic analysis.

Component	Price ($)
PV system per m^2	635
BOS	1870
Installation	$.6/$W_P$
O&M	1% of initial
Repair and replacement	5%
Net discount rate	5%
Minimum acceptable rate of return	5%

Table 5
Electricity sale price in the UAE.

Country	Generation cost $/kW h	Consumer cost $/kW h	Type	Consumer
Sharjah	0.059	0.040–0.13	Slab rate	All
Abu Dhabi	0.059	0.013	Flat	National
		0.043	Flat	None national

These values are obtained after converting the cost in local currencies to USD.

3.2. Economic assessment

Economic parameters such as electricity tariff, inflation rate and discount rate have strong impact on the value of PV power systems. Ignoring any of these parameters may make solar PV the greatest or worst opportunity of electricity generation [38]. In this study, the cost analysis is performed using data of initial costs related to the implementation of the proposed PV systems, prices and interest rates as shown in Tables 4 and 5. The PBT, NPV and IRR indices of the proposed PV systems are calculated as followed.

3.2.1. PBT index

The PBT is the minimum time it takes to recover investment costs. The technique used to obtain the PBT is simply to divide the cost of the PV system by the annual PV output plus savings in operating energy due to PV panels multiplied by the current electricity tariff. Fig. 5 shows the calculated PBTs based on Sanyo system (cost, efficiency and output), savings (replacement of construction materials and reduction in operating energy) and the current electricity tariff in the two studied emirates. As shown, the obtained PBTs are impracticable in terms of horizontal panels, except in the case of Sharjah. A different scenario occurs when tilted south-facing PV panels are concerned. All PBTs are less than the lifetime with the exception of electricity tariff for nationals in Abu Dhabi. Assuming 25 years as the lifetime of the PV system, the PBT in Sharjah is the shortest at 6.5 years with tilted south facing PV panels. The PBTs of nationals in Abu Dhabi are the longest at 138 (horizontal panels) and 65 years (south facing panels).

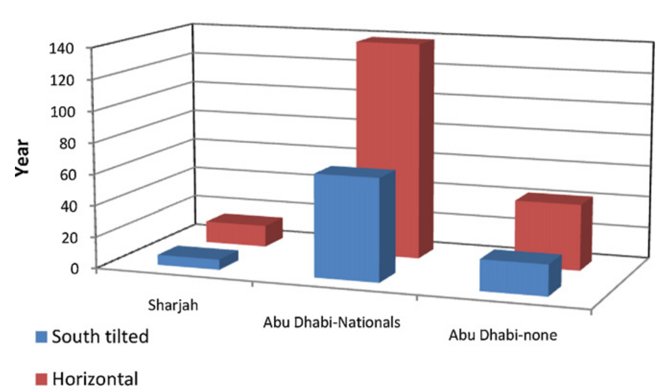

Fig. 5. PBT of each square meter of PV.

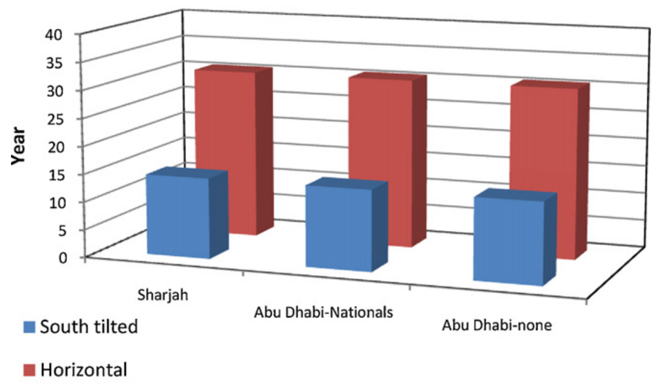

Fig. 6. PBT of each square meter of PV based on generation cost.

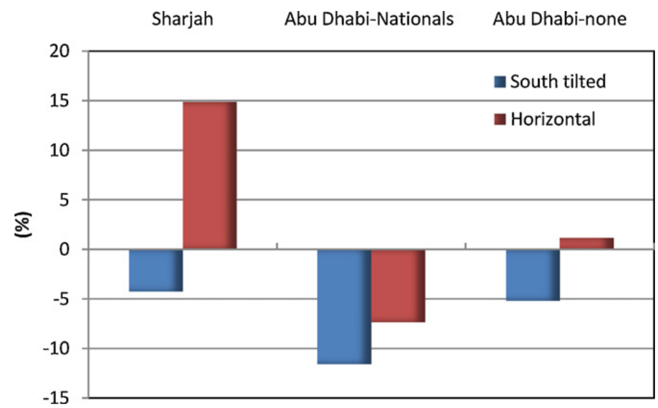

Fig. 8. IRR of each square meter of PV.

Although the difference in PV electricity outputs and savings in the two emirates is not large, electricity tariff play an important role in the cost-effectiveness of BiPV systems. The current low electricity tariff in Abu Dhabi seems not to be encouraging the search for other cheaper energy technologies that might look more attractive at this time. The electricity tariff in Abu Dhabi is subsidised and based on a cost accounting approach and do not reflect the true cost incurred in generating, transmitting and distributing a kilowatt-hour of electricity at the consumer end. It is clear, therefore, that as the electricity tariff increases the PBT is reduced. In the current case, the difference in electricity tariff between nationals and non-nationals leads to a variation in the PBT values. This is simply because electricity tariff determines the yearly cost saving. To emphasis the impact of electricity tariff on the PBT, the cost of electricity generation is used as electricity tariff. Fig. 6 shows the PBT considering the generation cost as electricity tariff. It is clear that the electricity sale price has a significant influence on the PBT value. The PBT of Sharjah, in this case, is longer than in the case of current electricity tariff because the government of Sharjah charges residents 0.13 $/kW h, while the generation and other costs is averaging 0.059 $/kW h.

3.2.2. NPV index

The NPV of the investment is a measure of the absolute gain over the whole life of the PV project. A system is cost-effective if the net saving or net benefit is positive. Fig. 7 illustrates the results of NPV calculations for the two studied emirates. All net benefits of NPVs are negative, except in the case of south tilted PV panels installed in Sharjah with values of $634. The remaining cases have negative values ranging from −$41 to −$553. It is clear, therefore, that only the south tilted PV panels in Sharjah can be considered as a cost-effective option.

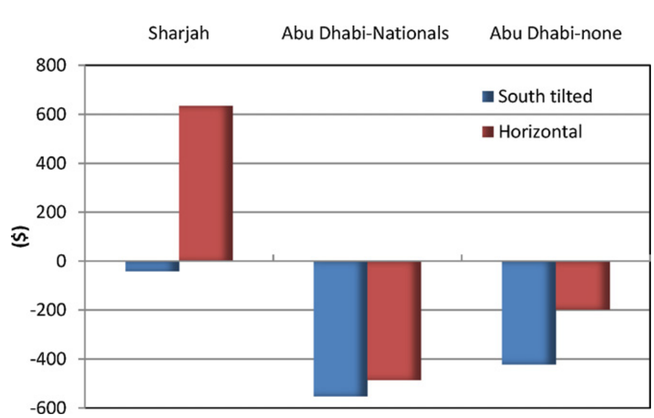

Fig. 7. NPV of each square meter of PV.

3.2.3. IRR index

IRR is used to focus on the rate at which benefits are realised following an initial investment. If IRR is equal to or greater than the required rate of return (in this case is 5%) then the development of the BiPV system will likely be considered financially acceptable. Fig. 8 shows the calculated IRRs for the two emirates. The maximum IRR of 14.9% is observed in Sharjah, while 1.15% is noted in Abu Dhabi (non-nationals) with respect to south-facing PV tilted panels. At the same time the IRRs of Sharjah and Abu Dhabi with respect to the horizontal PV panels are less than zero. Obviously, only the development of BiPV system with south-facing PV tilted panels in Sharjah is likely to be considered financially acceptable.

Clearly, the obtained economic indices demonstrate the cost effectiveness of the BiPV technology in Sharjah. While at the same time such a technology is found to be not a good economic option for Abu Dhabi and similar emirates based on the current electricity tariff, PV system cost and PV system efficiency.

4. Discussion

The assessment of technical aspects and economic cost may lead to the conclusion that the PV technology is not a cost-effective option. However, the PV market in the UAE is flourishing. It is logical therefore; that there are other aspects that influence the PV value and guide decisions of policy regarding the PV technology: firstly, ambitions represented by the desire of Abu Dhabi government to play a very active role in reducing the CO_2 emissions and to receive publicity and recognition in the field of environmental policy. The UAE is amongst the top countries in terms of CO_2 emissions per capita. In addition, the current reports on environmental policy are very critical and have given the UAE the image of being one of the worst environmental polluters worldwide. Reducing green house gases (GHG), particularly CO_2 emissions, thereby, is essential to improve such an image. Using BiPV systems can reduce the CO_2 emissions. Each single watt generated or saved by the PV technology significantly reduces the amount of CO_2 emitted by the ordinary central power plant. Each square meter of BiPV is capable of making a reduction of approximately 195 gCO_2/yr. Reducing the electricity generation from such power plants will decrease the CO_2 emissions and limit the effect of global warming on the UAE. From this perspective, reducing CO_2 emissions has become a target for the UAE, particularly for the government of Abu Dhabi. This is very obvious in the massive utilisation of solar energy and low carbon emission technologies, not only through the establishment of sole energy power plants, but also through the construction of green and

sustainable buildings. In addition, many initiatives and attempts have been made to impress the world with records. For instant, two huge and costly projects are planned to be completed in the next few years. The first is a $350 millions solar power plant. The second is a $2 billions hydrogen-fuelled power plant. Such projects are supposed to contribute to the sustainable development including economic, environmental and technological well being. They will not only contribute towards employment generation, but also reduce significant amount of GHG emissions which would have taken place in ordinary power plant scenario with natural gas and fuel oil based generation. In the latter project, the CO_2 will be kept underground which represent one of the world first carbon capture and storage projects. Secondly, the trade-off between economic costs and environmental benefits seems to stimulate decisions of UAE policy regarding the PV technology on the grounds that adoption of such a technology will have social benefits outside the margin of cost consideration. The above economic assessment revealed that BiPV systems are not viable in the Emirate of Abu Dhabi and others with similar situation. Such systems cannot compete with conventional electricity sources on a unit cost basis. Thereby, a promotion of financial subsidy on PV cost can encourage the adoption of PV technology by the consumers and lead to reduce the overall electricity consumption. The installation of PV systems can change electricity consumption behaviour. This is simply because having the PV system as an electricity generator will influence the concern for electricity use and serve as an educational source. In the case of grid-connected PV systems, the amount of electricity that will feed into the grid can be maximised and many benefits can be gained to support the public grid. From this perspective, individual systems such as the BiPV seem to be more beneficial for the UAE than central PV power systems. To bring about the benefits of PV electricity for the UAE residential sector, therefore, the first and most practical step is to implement a continuous promotion strategy that consists of both subsidies for investments and fair electricity tariff.

5. Conclusion

This paper has cast light on the use of PV systems in the UAE. Large scale applications of PV have been the focus of many initiatives with emphasis on technical and economic aspects. The value of PV technology needs to be evaluated in the light of many aspects including environmental and even social parameters. This study examined technical, economic and environmental parameters that influence the use of PV in the UAE. It assessed the trade-off between environmental benefits and economic cost of BiPV technology applied into the UAE residential sector. The cost analysis in this paper can lead to the conclusion that, except for a few emirates in the UAE, there is no incentive for the government and consumers to apply PV systems for electricity generation. It was noted that the BiPV technology is more expensive than conventional technology in most grid-connected applications. However, the PV market in the UAE is booming. PV technology is seen as viable in a way that it can provide significant environmental benefits over the conventional power plants. Each single watt generated or saved by the PV technology significantly reduces the amount of CO_2 emissions from ordinary central power plants. Reducing the electricity generation from such power plants will decrease the CO_2 emissions and limit the effect of global warming on the UAE and others. The trade-off between economic cost and environmental benefits justifies the support of UAE policy for the PV technology on the bases that adoption of such a technology will have social benefits beyond the cost consideration. The installation of BiPV systems can reduce the overall electricity consumption by increasing the concern for electricity use and serving as an educational source. This study, therefore, suggested that BiPV systems offer more cost reductions in both energy and economic terms over centralised PV plants, especially if the costs of saved operating energy and avoided building materials are taken into account. To be a cost-effective option, therefore, subsidies for PV investments and reasonable electricity tariff must be implemented.

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